Fast Target Detection Framework for Onboard Processing of Multispectral and Hyperspectral Images

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1. Contents

2. Research Objectives

- Develop a robust, automated, and real-time target detection system under varying illumination, atmospheric conditions and target/sensor viewing geometry.
- Demonstrate the feasibility of the system using actual and/or simulated data.

3. Technical Approach

Fast target detection framework

- Conventional target detection is done in the reflectance domain: a lot of computations due to atmospheric compensation, not suitable for onboard processing, difficult to change mission goals during mission.
- Our approach is done in the radiance domain. Only a few target signatures (reflectance) need to be transformed to the radiance domain. This is very suitable for onboard processing such as search and rescue missions.
- JHU/APL developed a similar approach that uses MODTRAN and AFWA MM5. Our approach was motivated by [1], which is a hybrid framework that uses MODTRAN and a nonlinear analytical model.

[*1] "Hyperspectral material identification on radiance data using single-atmosphere or multiple-atmosphere modeling," Adrian V. Mariano ; John M. Grossmann, J. Appl. Remote Sens. 4(1), 043563 (November 23, 2010).

3. Technical Approach

- **Radiance equation model parameter estimation using MODTRAN outputs [*1]**

$$L = \frac{A\rho}{1-\rho_A S} + \frac{B\rho_A}{1-\rho_A S} + P - \alpha D\rho$$

L: Radiance

ρ : Material reflectance

ρ_A : Adjacent region reflectance

S : Spherical albedo

A,B : Coefficients that depend on atmospheric, geometric and solar illumination conditions

P : Path radiance

D : Radiance due to direct solar illumination

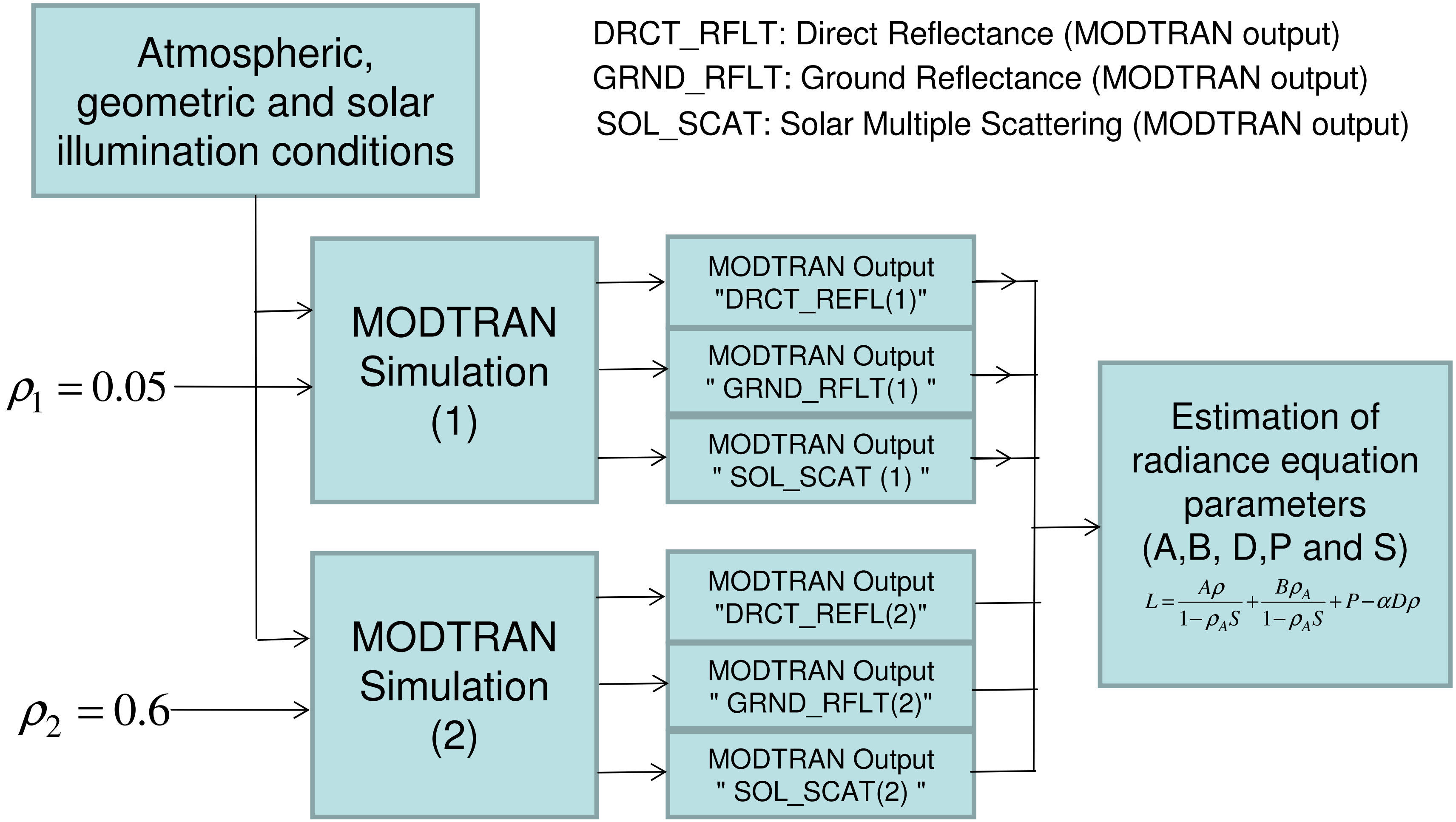
α : Amount of solar occlusion

[*1] "Hyperspectral material identification on radiance data using single-atmosphere or multiple-atmosphere modeling," Adrian V. Mariano ; John M. Grossmann, J. Appl. Remote Sens. 4(1), 043563 (November 23, 2010).

3. Technical Approach

- **Radiance equation model parameter estimation using MODTRAN outputs [*1]**

DRCT_RFLT: Direct Reflectance (MODTRAN output)
GRND_RFLT: Ground Reflectance (MODTRAN output)
SOL_SCAT: Solar Multiple Scattering (MODTRAN output)



[*1] "Hyperspectral material identification on radiance data using single-atmosphere or multiple-atmosphere modeling," Adrian V. Mariano ; John M. Grossmann, J. Appl. Remote Sens. 4(1), 043563 (November 23, 2010).

3. Technical Approach

- **Radiance equation model parameter estimation using MODTRAN outputs [*1]**

$$L = \frac{A\rho}{1-\rho_A S} + \frac{B\rho_A}{1-\rho_A S} + P - \alpha D\rho$$

Suppose $C_{\rho 1} = SOL\_SCAT(1)$ and $G_{\rho 1} = GRND\_RFLT(1)$, and

$C_{\rho 2} = SOL\_SCAT(2)$ and $G_{\rho 2} = GRND\_RFLT(2)$

Then, $G_{\rho 2} = \dfrac{A\rho_2}{1-\rho_2 S}$, $C_{\rho 2} = \dfrac{B\rho_2}{1-\rho_2 S} + P$ and $G_{\rho 1} = \dfrac{A\rho_1}{1-\rho_1 S}$, $C_{\rho 1} = \dfrac{B\rho_1}{1-\rho_1 S} + P$

The radiance model parameters can then be found as:

$$D = \mathrm{DRCT\_RFLT}(1)/\rho_1 = \mathrm{DRCT\_RFLT}(2)/\rho_2$$

$$S = \frac{G_{\rho 2}/\rho_2 - G_{\rho 1}/\rho_1}{G_{\rho 2} - G_{\rho 1}} \qquad B = (C_{\rho 1} - P)\left(\frac{1}{\rho_1} - S\right)$$

$$A = \frac{G_{\rho 2}}{\rho_2} - G_{\rho 2} S \qquad P = \frac{S(C_{\rho 1} - C_{\rho 2}) + C_{\rho 2}/\rho_2 - C_{\rho 1}/\rho_1}{1/\rho_2 - 1/\rho_1}$$

[*1] "Hyperspectral material identification on radiance data using single-atmosphere or multiple-atmosphere modeling," Adrian V. Mariano ; John M. Grossmann, J. Appl. Remote Sens. 4(1), 043563 (November 23, 2010).

3. Technical Approach

Advantages of the proposed system

- Eliminates the need of applying atmospheric correction on the whole image cube and instead simulates the variants of the radiance signature of the target of interest and searches for these signatures in the test radiance image cube
- The effects of different illumination, atmospheric conditions, occlusion and varying sensor/target viewing geometries are taken into effect during the simulation of the radiance spectral profiles of the target of interest
- Allows generation of look-up tables for several radiance signature variants of the target which will reduce computation/processing time for target detection in operations like “search and rescue” that require quick on-board decisions

4. Results

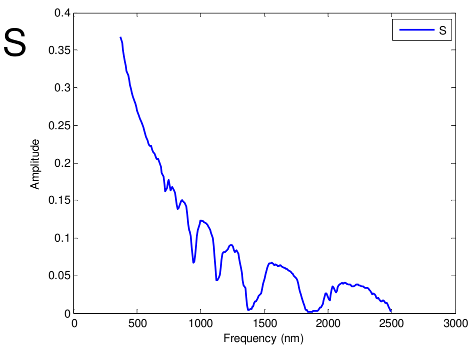
- **Demonstration of radiance model parameter estimation and simulating radiance profiles with the model parameter estimates**

Atmospheric, solar illumination and geometric location parameters used in two MODTRAN runs to estimate model parameters (S, A, P, D, B)

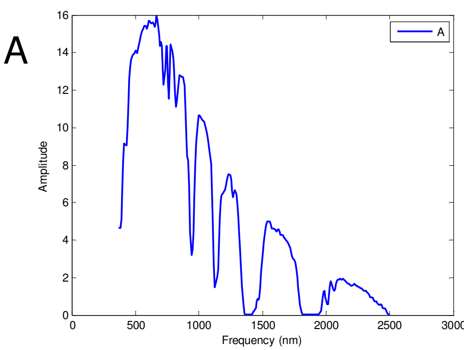
Model	Tropical
IHAZE	Rural
VIS	5 km
H2OSTR	0.5
Altitude	1 km
Approximate observer position	Latitude: 39.3305º (N), Longitude: 76.2879 (W)
Date	August 29, 1995
Time data collected	18:37 UTC

Plots of estimated model parameters (S, A, P, D, B)

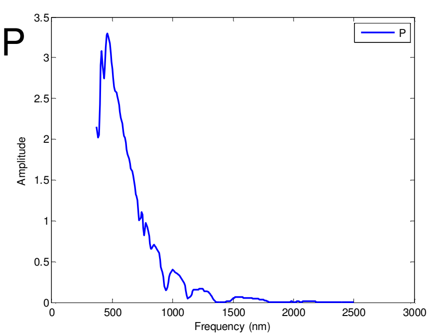
S



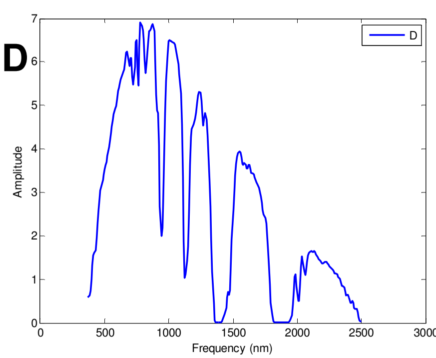
A



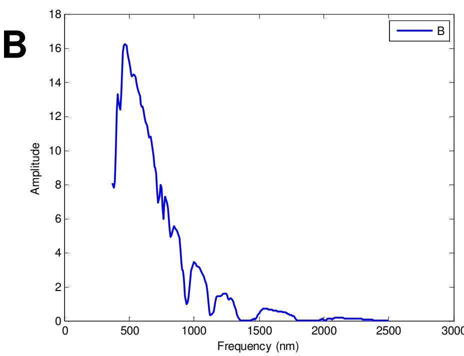
P



D



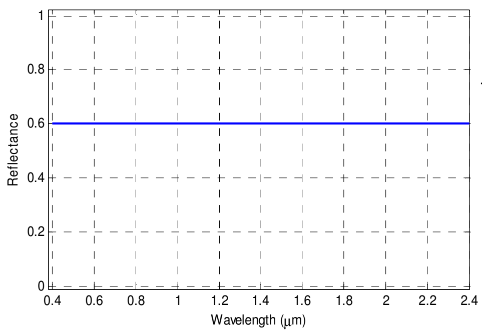
B



4. Results

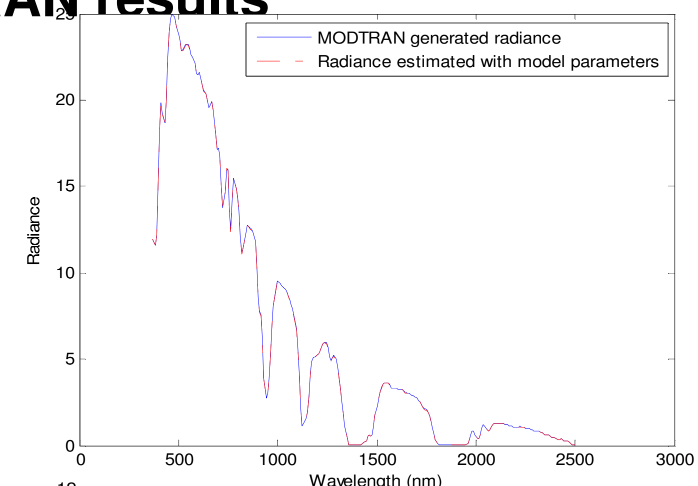
- **Comparing the simulated radiance profiles (from the model parameter estimates) with the MODTRAN results**

Case 1 (fixed reflectance of 0.6)

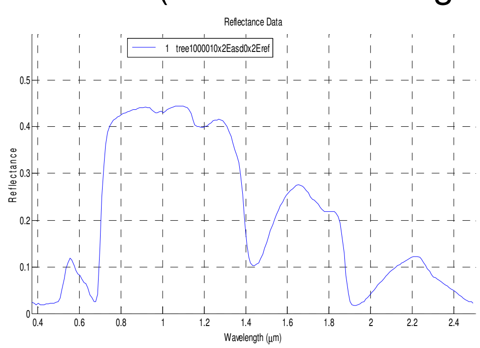


MODTRAN

Radiance model with estimated parameters

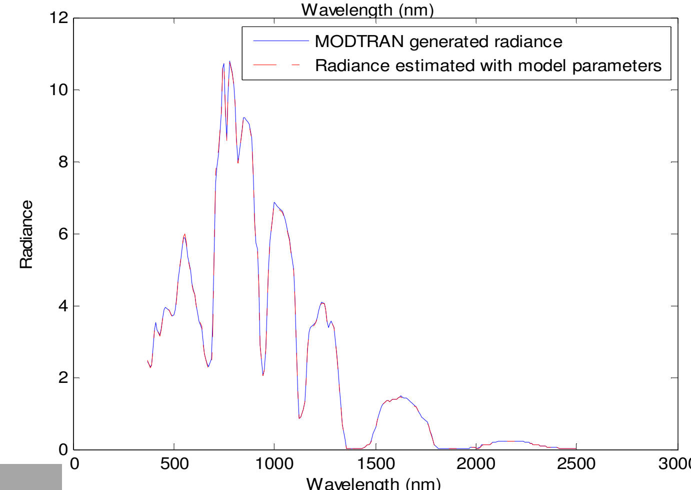


Case 2 (reflectance of a green tree)



MODTRAN

Radiance model with estimated parameters



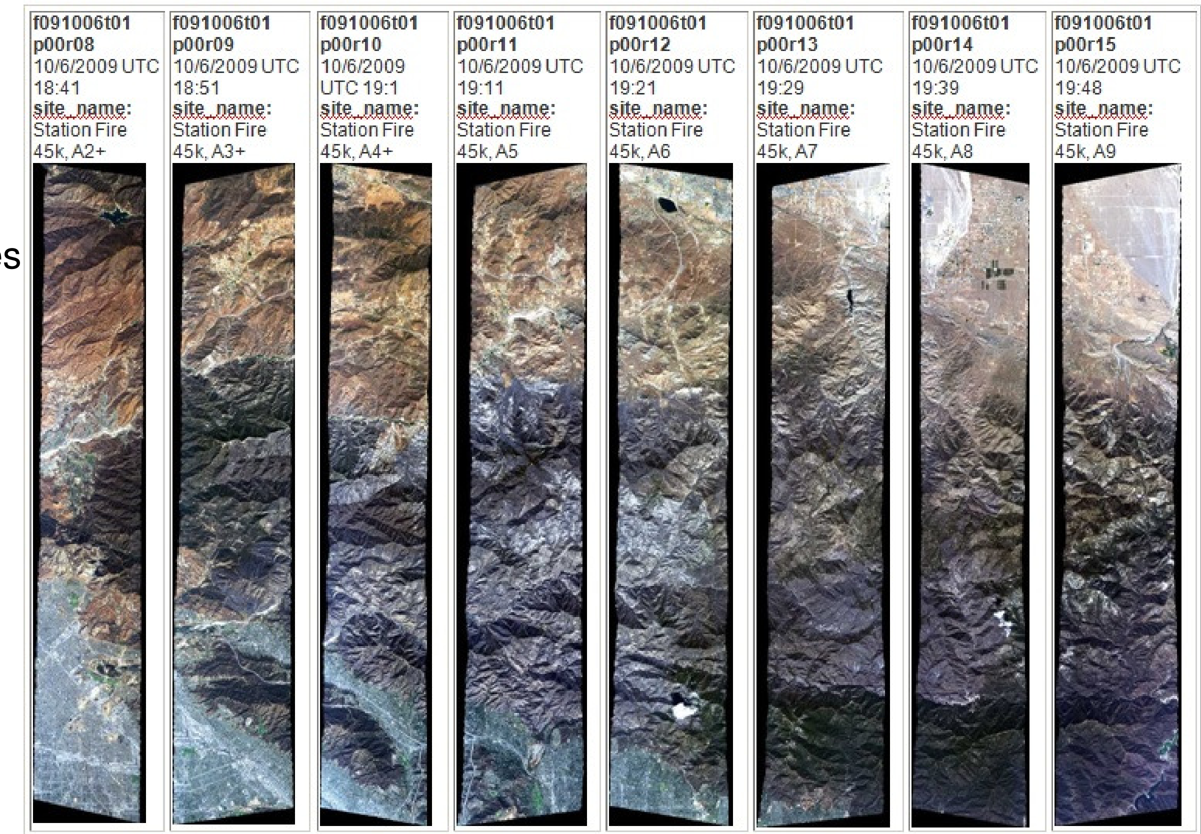
The results are almost identical which shows that radiance model parameter estimation is successful !

4. Results

- **AVIRIS data for Los Angeles Station Fire (Aug 2009) to detect burnscar**

The Station Fire took place between August 26 and October 16, and a total of 160,577 acres (251 sq mi; 650 km^2) were affected, 209 structures had been destroyed, including 89 homes [*2]. It first started in the Angeles National Forest near the U.S. Forest Service ranger station on the Angeles Crest Highway (State Highway 2) [*2].

AVIRIS images acquired on October 6, 2009 (fire is mostly over)



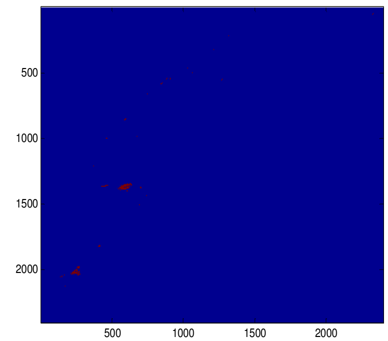
[*2] http://en.wikipedia.org/wiki/2009_California_wildfires

4. Results

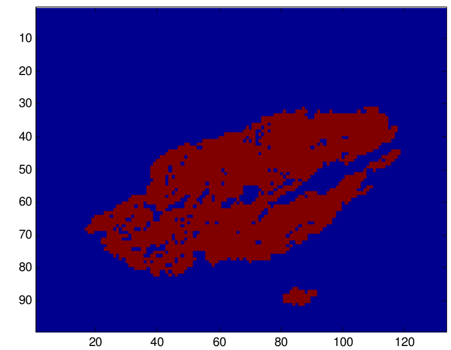
- **Getting groundtruth of burned locations for AVIRIS data using MODIS MCD45A1 product**

MODIS H8-V5 tile (Los Angeles region falls into this tile)

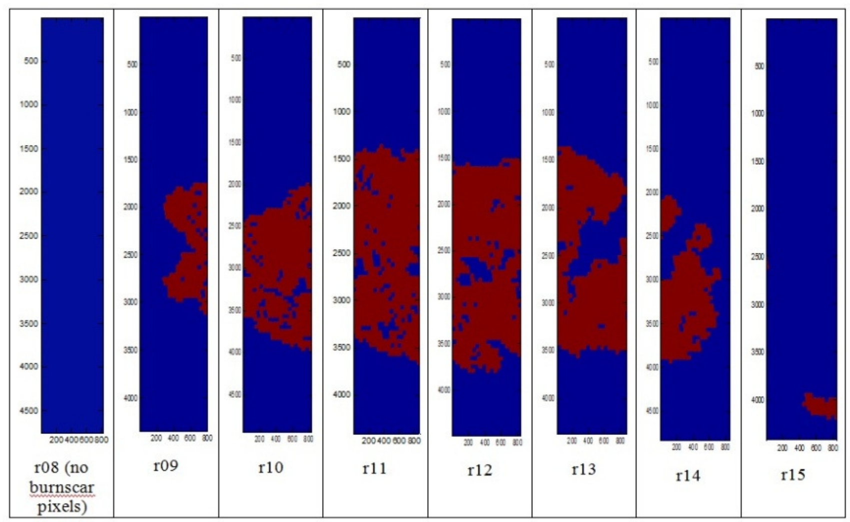
MCD45A1 burned area product for this tile for Sep 2009 (red pixels indicate burned areas)



Zoom into the region for the LA Station Fire in MCD45A1 product



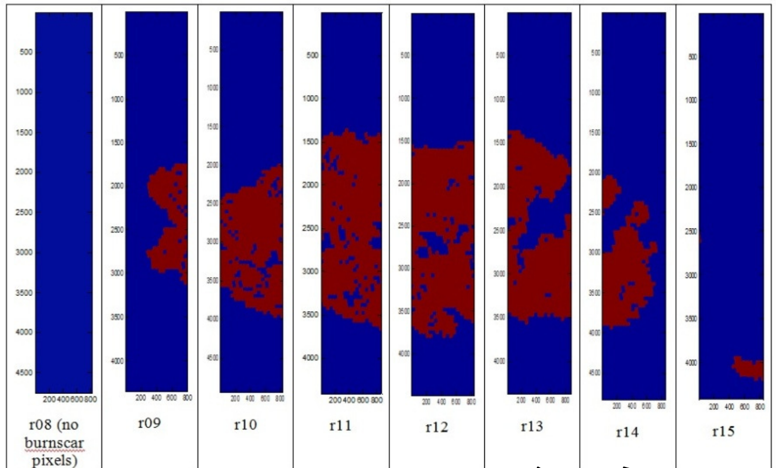
Based on AVIRIS image data coverage for each strip the groundtruth maps for burned area are extracted



4. Results

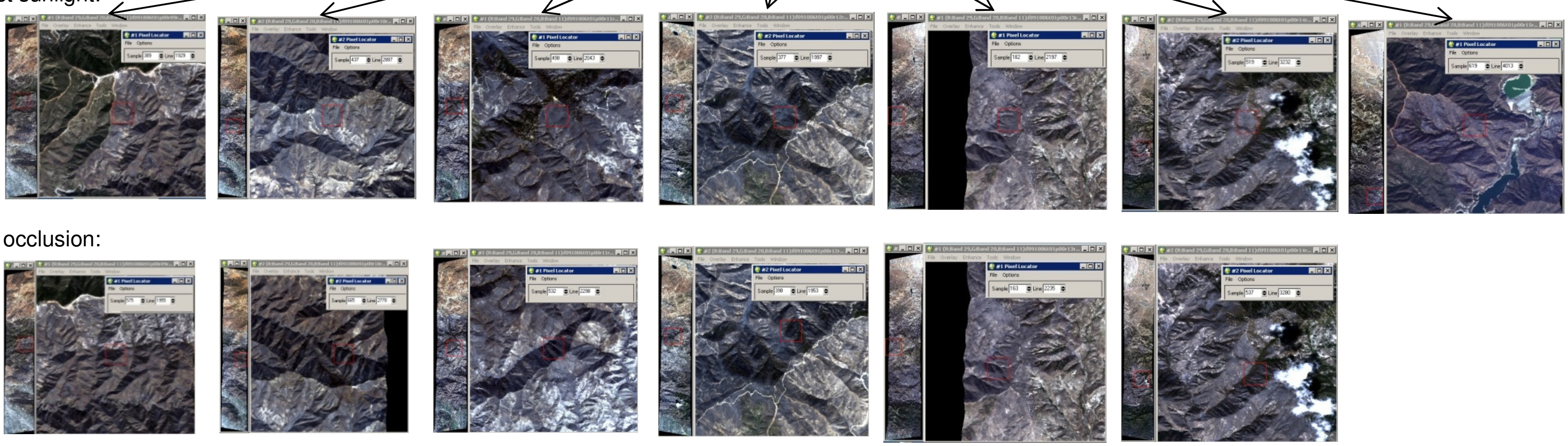
- **Burnscar pixel selections from AVIRIS image strips**

Based on extracted groundtruth maps and also visual examination, burnscar pixels are selected from each AVIRIS image data (pixels with direct sunlight and under shadow with some occlusion)



Direct sunlight:

With occlusion:



r09 r10 r11 r12 r13 r14 r15

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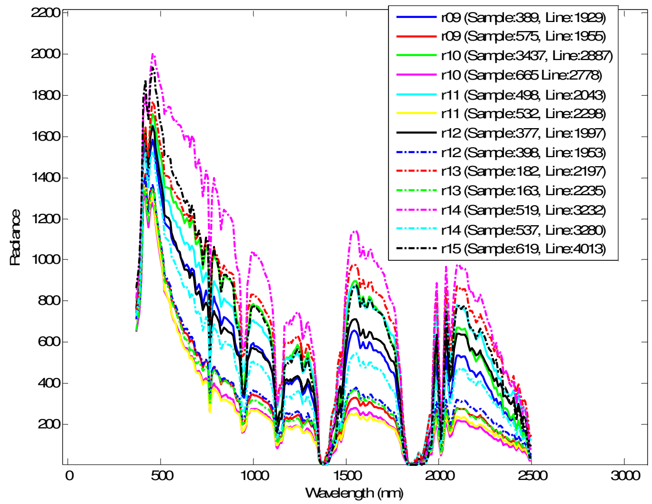
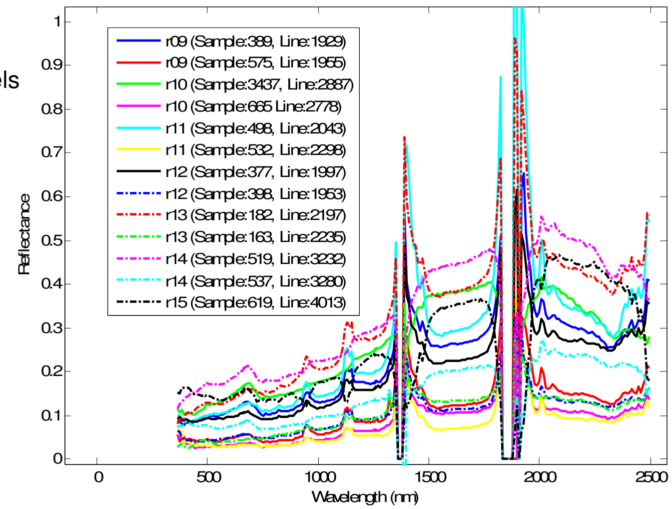
4. Results

- **Radiance and reflectance signatures of selected burnscar pixels**

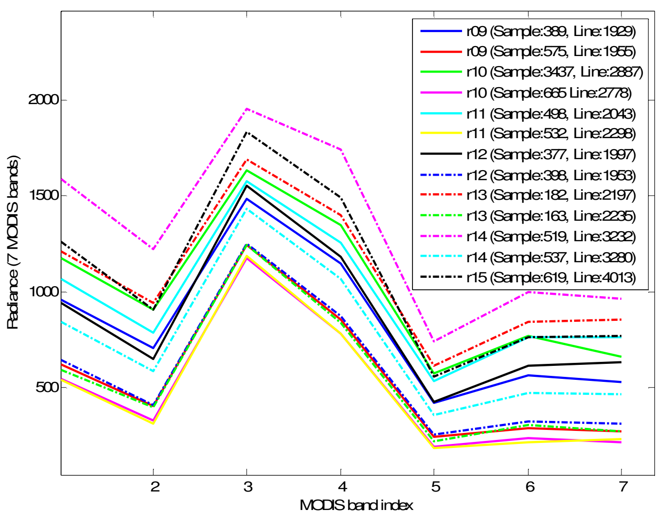
Actual radiance signatures of selected pixels (in DN)



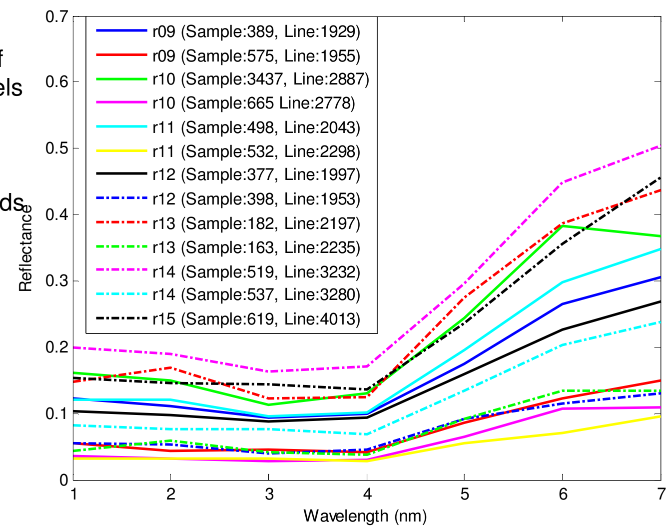
Reflectance signatures of selected pixels (after QUAC atmospheric correction)



Actual radiance signatures of selected pixels (in DN) for MODIS bands only



Reflectance signatures of selected pixels after QUAC atmospheric correction (MODIS bands only)



MODIS bands: 648 nm, 858 nm, 470 nm, 555 nm, 1240 nm, 1640 nm, and 2130 nm (In target detection investigations in this work, we used the 7 bands that are closest to these MODIS bands)

4. Results

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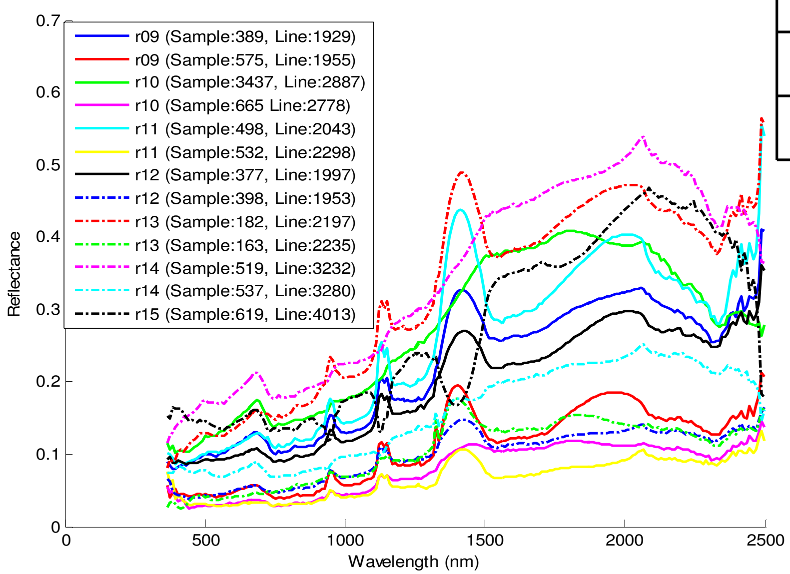
- **Atmospheric, illumination and geometric location conditions used in radiance model parameter estimation and simulation of radiance signatures for the selected reflectance profiles**

Geometric locations of the AVIRIS image strips and corresponding UTC values

AVIRIS Image Strip	Min Lat	Min Long	Max Lat	Max Long	UTC	Ground Elevation (km)
r09	34.1436	-118.376	34.5639	-118.276	18:51	0.67
r10	34.1488	-118.31	34.6222	-118.208	19:01	0.93
r11	34.152	-118.236	34.5625	-118.133	19:11	0.98
r12	34.1571	-118.165	34.5788	-118.066	19:21	1.11
r13	34.1603	-118.091	34.5626	-117.99	19:29	1.22
r14	34.1575	-118.022	34.5984	-117.924	19:39	1.17
r15	34.1634	-117.943	34.563	-117.847	19:48	1.18

Variants of selected burnscar reflectance profiles (based on QUAC)



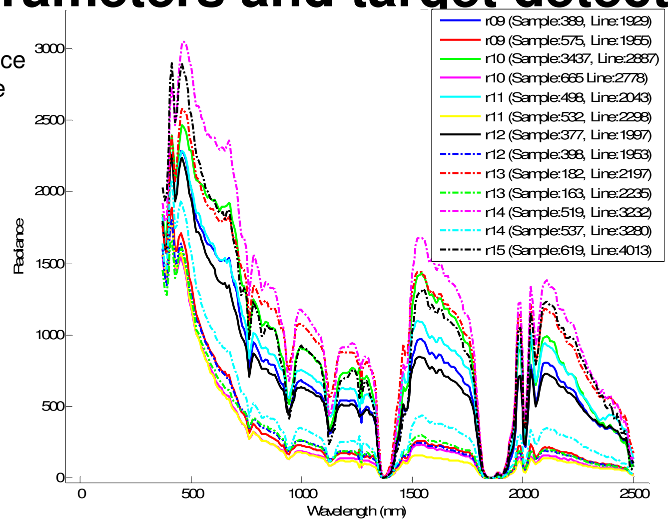
Atmospheric and time/date conditions

Model	Mid Latitude Summer (MODEL = 2)
VIS (Visibility)	20 km
H2OSTR (Water vapor)	0.270
IHAZE	Rural (IHAZE =1)
Altitude	14 km
Observer position	(see above table for observer positions)
Data collection day	Oct 6, 2009
Data collection time	(see above table for UTC times)

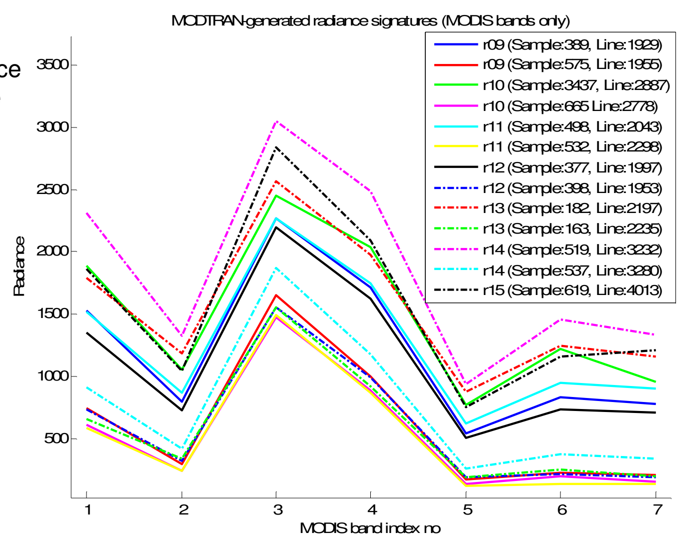
4. Phase 1 Results

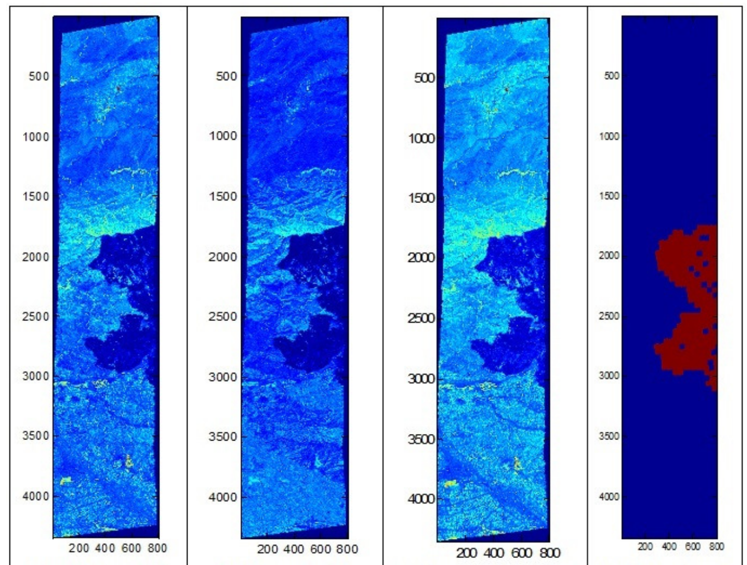
- **Simulated radiance signatures with estimated radiance model parameters and target detection results**

Simulated radiance signatures for the selected pixels



Simulated radiance signatures for the selected pixels (MODIS bands only)





(a) Using actual radiance signatures (b) Using actual reflectance signatures (c) Using simulated radiance signatures (d) Groundtruth

Target detection score images with M-SAM for "r09" using simulated radiance signatures, using actual radiance signatures and using actual reflectance signatures with QUAC (groundtruth map for "r09" image is also shown). In target detection, we used the 7 MODIS bands only.

$$SAM(\mathbf{s}_i, \mathbf{r}_j) = \cos^{-1}\left(\frac{\langle \mathbf{s}_i, \mathbf{r}_j \rangle}{\|\mathbf{s}_i\| \|\mathbf{r}_j\|}\right)$$

$$\text{M-SAM}(\mathbf{s}_i, \text{burnscar}) = \min(SAM(\mathbf{s}_i, \mathbf{r}_1), SAM(\mathbf{s}_i, \mathbf{r}_2), ..., SAM(\mathbf{s}_i, \mathbf{r}_K))$$

where $\text{burnscar} = \{\mathbf{r}_1, \mathbf{r}_2, ..., \mathbf{r}_K\}$

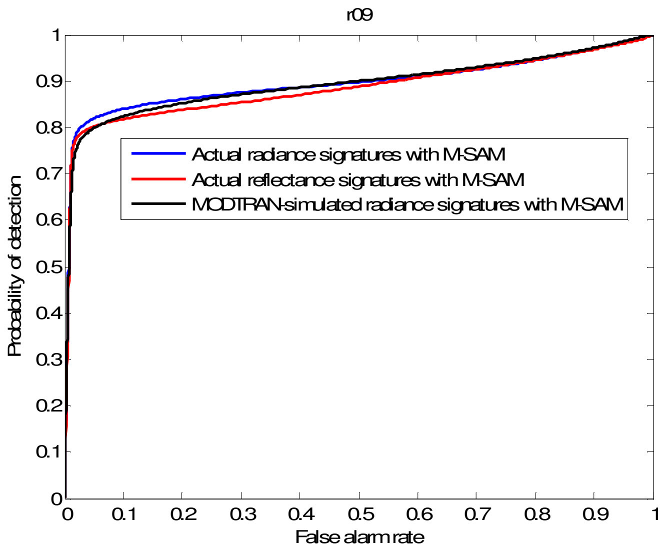
$\mathbf{s}_i$ = test pixel spectral profile

$\mathbf{r}_j$ = burnscar signature variant

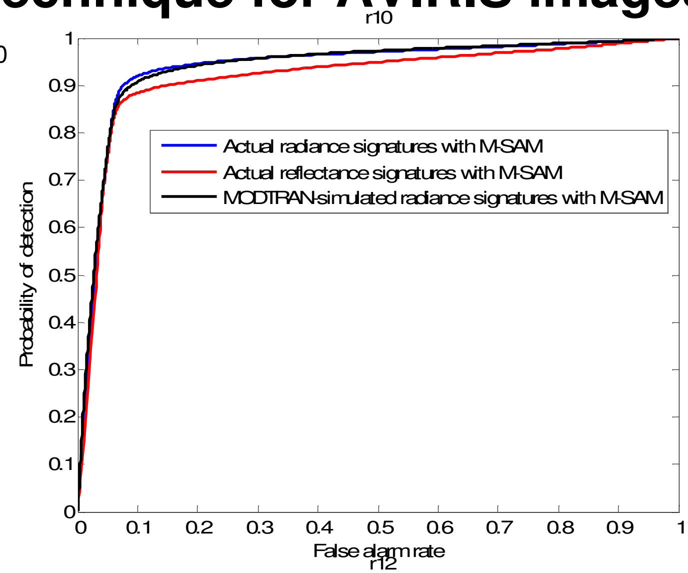
4. Results

- **ROC curves with M-SAM detection technique for AVIRIS images**

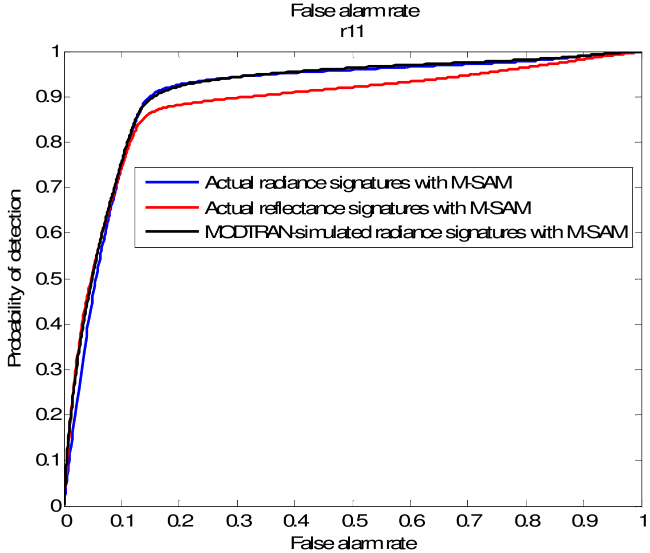
r09



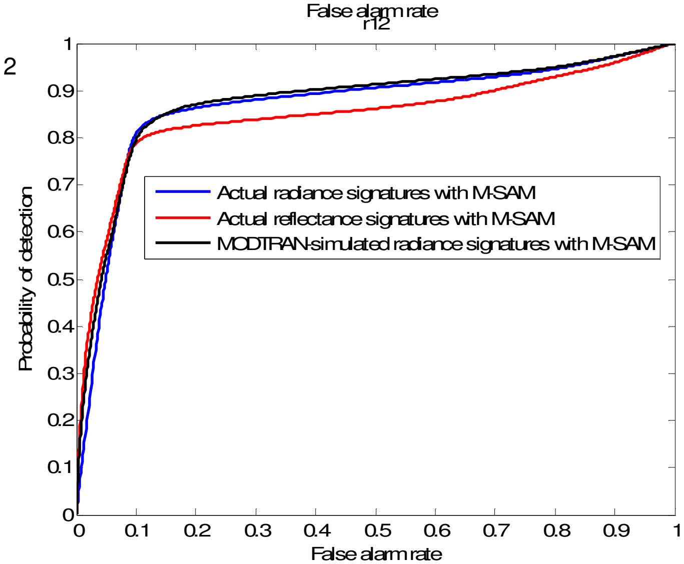
r10



r11



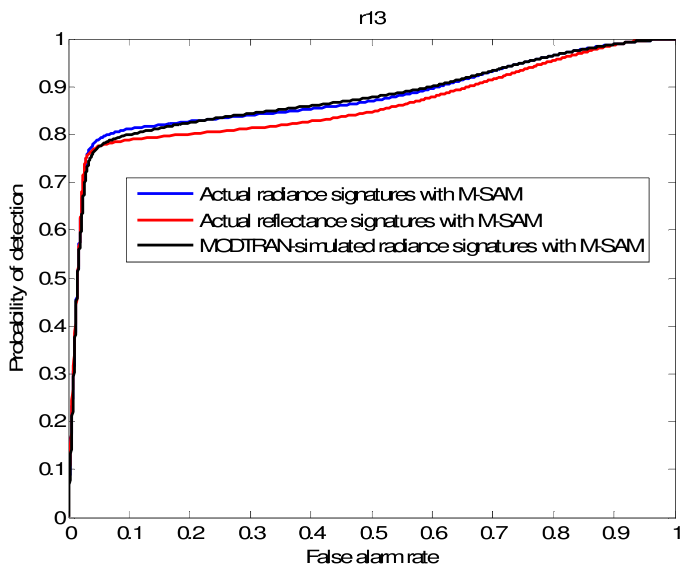
r12



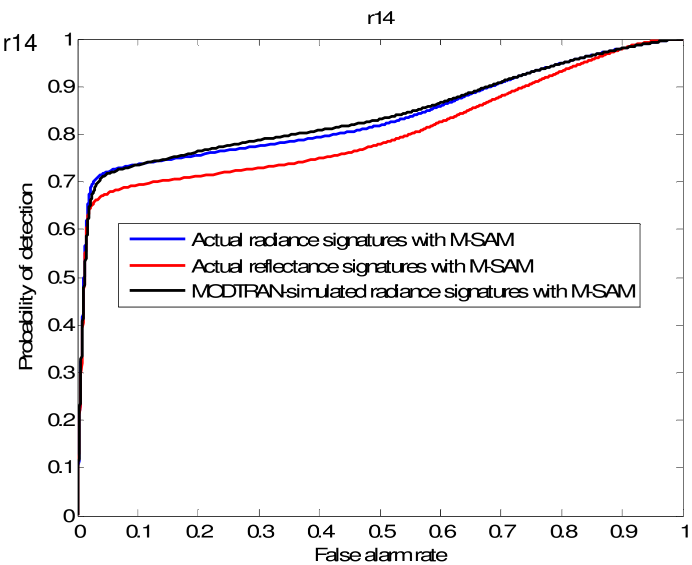
4. Results

- **ROC curves with M-SAM detection technique**

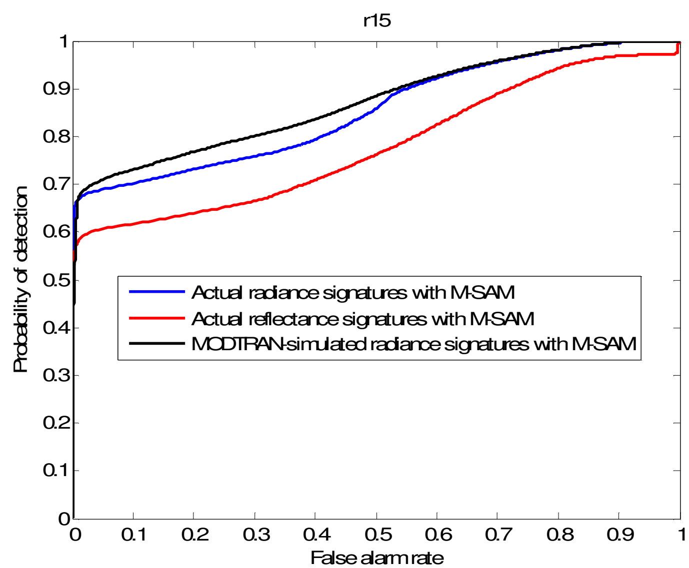
r13



r14



r15



4. Results

- **AUC (Area under curve) measures from ROC curves**

AVIRIS Filename	Analysis Type	Using actual radiance signatures (*target detection in radiance domain*)	Using QUAC reflectance signatures (*target detection in reflectance domain*)	Using simulated radiance signatures (reflectances are from QUAC) (*target detection in radiance domain*)
r09	AUC(overall)	0.8958	0.8856	0.8935
	AUC(partial)	0.0761	0.0750	0.0745
r10	AUC(overall)	0.9395	0.9183	0.9400
	AUC(partial)	0.0655	0.0612	0.0653
r11	AUC(overall)	0.9028	0.8814	0.9087
	AUC(partial)	0.0427	0.0472	0.0471
r12	AUC(overall)	0.8696	0.8487	0.8783
	AUC(partial)	0.0473	0.0544	0.0514
r13	AUC(overall)	0.8772	0.8601	0.8771
	AUC(partial)	0.0691	0.0679	0.0676
r14	AUC(overall)	0.8370	0.8055	0.8415
	AUC(partial)	0.0648	0.0631	0.0659
r15	AUC(overall)	0.8536	0.7794	0.8713
	AUC(partial)	0.0676	0.0585	0.0687

Overall: Whole ROC curve is used in AUC computation
Partial: ROC curve up to a false alarm rate of 0.1 is used in AUC computation

4. Results

- **Observations**

  - With the simulated radiance signature library using estimated radiance models, we observed detection performances close to the detection performance obtained with using actual radiance signatures that are retrieved from actual images and in some cases slightly better than those.

  - It is possible that if a better set of MODTRAN parameters has been selected in the radiance model parameter estimation that fully complies with the atmospheric conditions during the actual data acquisition, or a more realistic set of reflectance signature variations for burnscar has been used, the detection performances could perhaps be further improved.

  - These results are found highly promising in demonstrating the feasibility and effectiveness of the proposed fast target detection idea.